Bounding New Physics using the Tevatron Higgs Exclusion Limit

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Outline

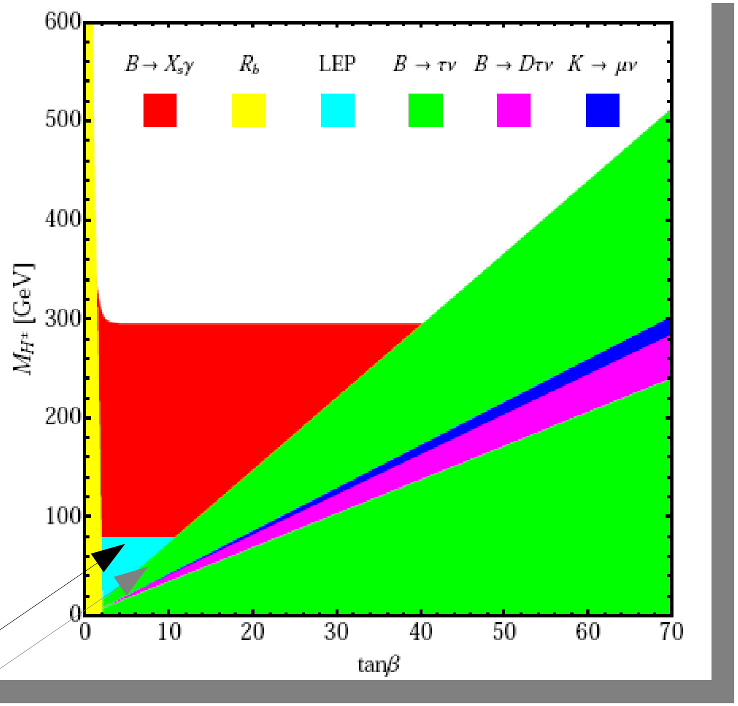
- Motivations: strength of indirect constraints
- Review of Higgs production via gluon fusion
- Looking beyond the Standard Model with the Higgs:

  colored scalars
- Conclusions

Direct vs. Indirect Constraints: charged Higgs in type II THDM

The mass of Charged Higgs boson in type II THDM has the strongest lower bound from $b \to s \gamma$ for $\tan\beta \leq 40$.

The indirect bound is stronger than the LEP direct bound.



LEP constraint

U. Haisch, arXiv:0805.2141

Direct vs. Indirect Constraints: Z' as an example

	EW	CDF	LEP 2
Z_χ	1,141	892	781 [21]
Z_ψ	147	878	481 [20]
Z_η	427	982	515 [21]
Z_{LR}	998	630	804 [20]
$Z_{\rm seq}$	1,403	1,030	1,787 [20]

Table 2: Lower mass limits for selected Z' bosons in GeV.

J. Erler
arXiv:0907.0883v1

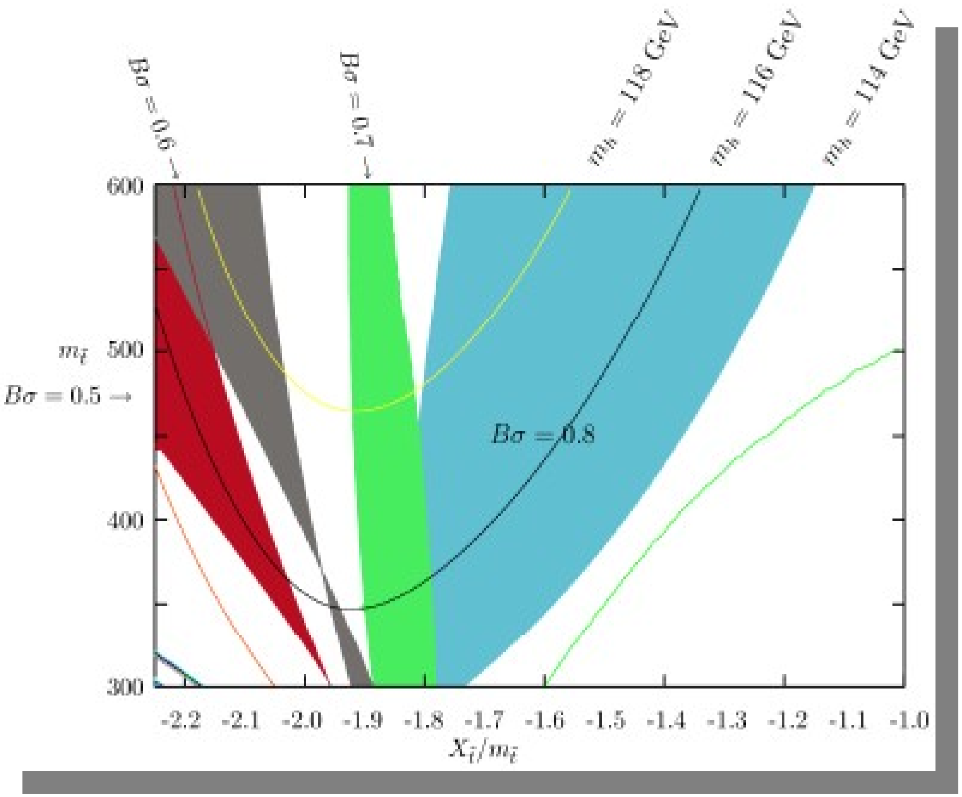
A global fit to EW precision observables provides stronger constraints on various Z' models than the direct search bounds

New physics and properties of the Higgs

New states can significantly modify the properties of the Higgs

MSSM I. Low, S. Shalgar 2009

$$g\, g \rightarrow h \rightarrow \gamma\, \gamma$$



The Higgs can be very different in models beyond the SM

Can we use the Higgs boson null search results at Tevatron to indirectly learn about possible new physics ?

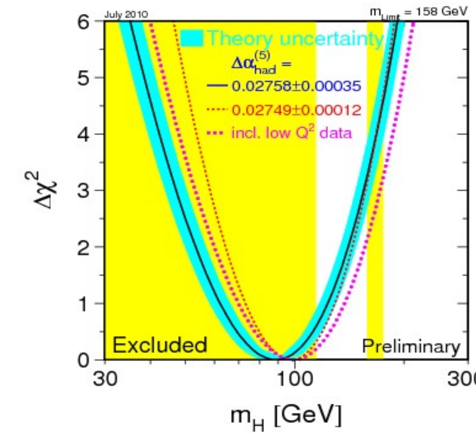
We need first to understand the Higgs in the SM

Current Limits on the SM Higgs Mass

Combined efforts from direct searches and theoretical predictions were needed to set tighter limits on MH

- Current fit of electroweak parameters by LEP EW-working group predicts:

$$M_H = 89^{+35}_{-26}\,GeV$$



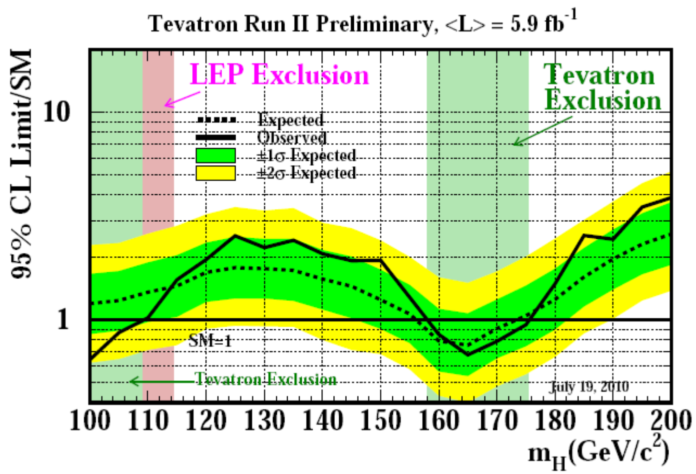
LEP EW working group July 2010

- Upper bound (from precision EW measurements) and lower bound (direct searches at LEP) at 95% CL (SM Higgs):

$$M_H < 158\,GeV$$

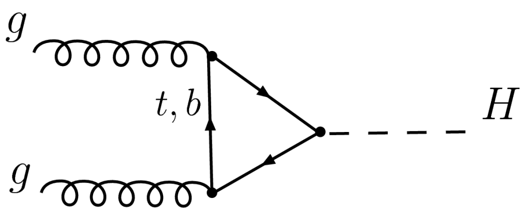
$$M_H > 114\,GeV$$

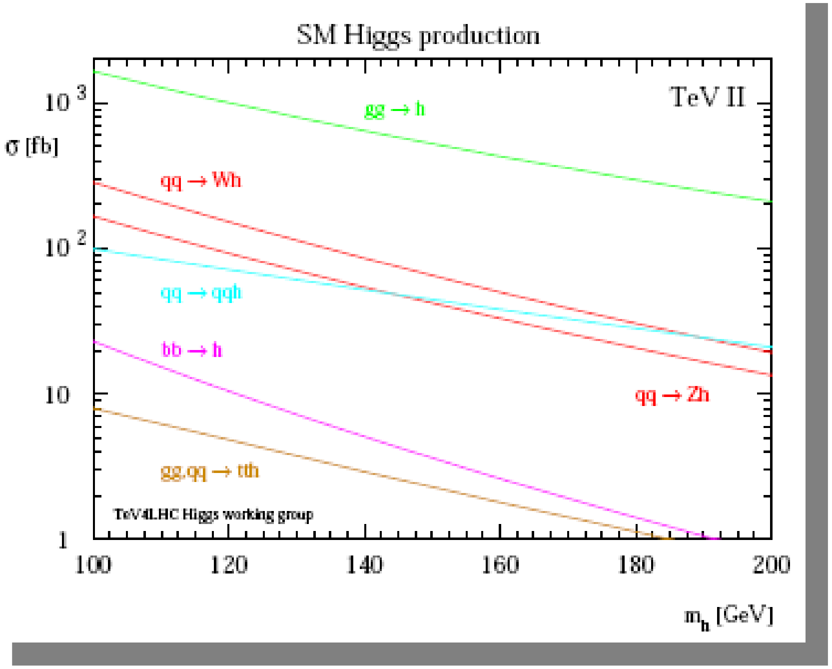
- Combined results from CDF and D0 excluded MH in the range 158-173 GeV and 100-109GeV at 95% CL arXiv:1007.4587

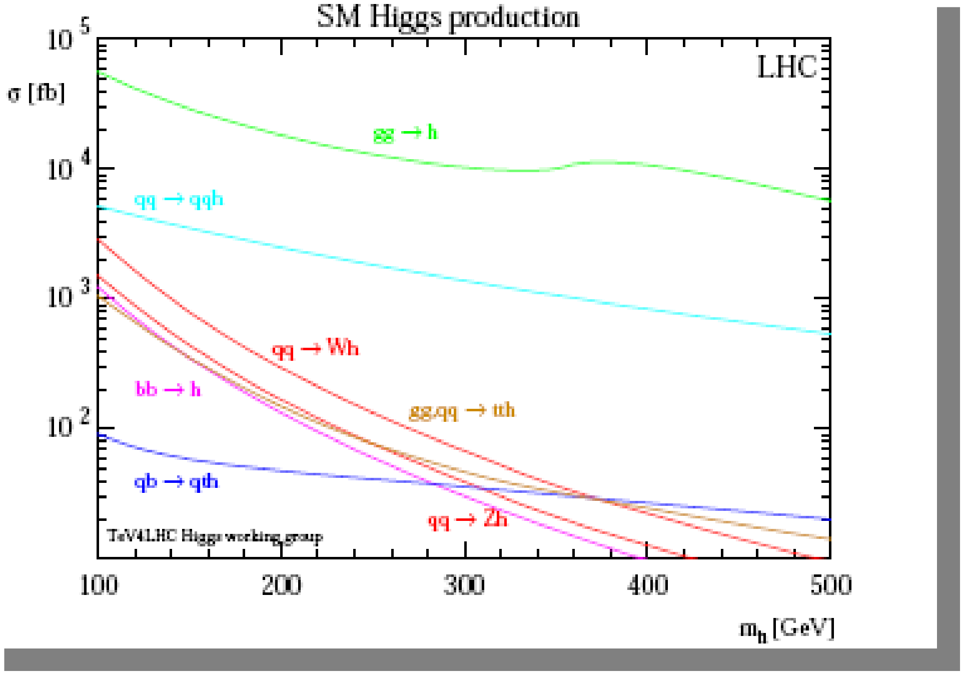


SM Higgs Production at Hadron Colliders

Gluon fusion is the dominant production
Mode in the SM at both colliders

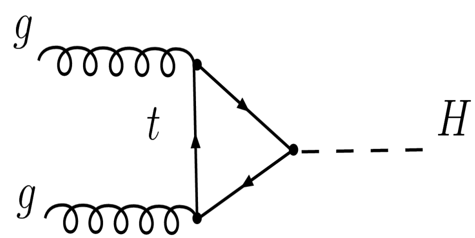




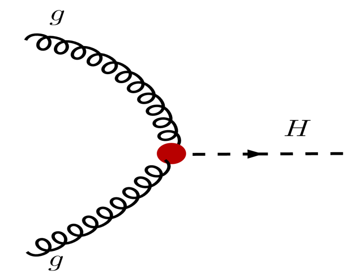


An Effective Theory for Higgs

In the limit where the top-quark is heavier than the Higgs and all other quarks are massless, integrate out the top and couple the gluons to the Higgs through an effective vertex:

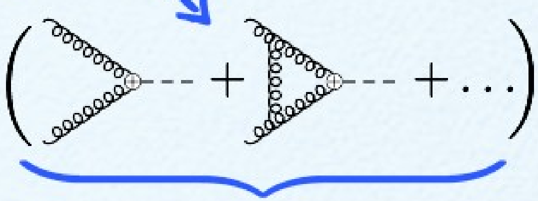


$2M_T > M_H$ $\longrightarrow$ $C(\alpha_s, M_t)$ x



$$\mathcal{L}_{eff} = -\frac{\alpha_S}{4v} C H G^a_{\mu\nu} G^{a\mu\nu}$$

$$\underbrace{\left(C_0 + \left(\frac{\alpha_s}{\pi}\right) C_1 + \left(\frac{\alpha_s}{\pi}\right)^2 C_2 + \dots\right)}_{\text{Model dependent (top quark + anything)}}$$



QCD only

Factorization of QCD and model dependent effects

$C(\alpha_s)$ Known in SM through α_s^5 Schroder, Steinhauser (2006); Chetyrkin , Kuhn, Sturm (2006)

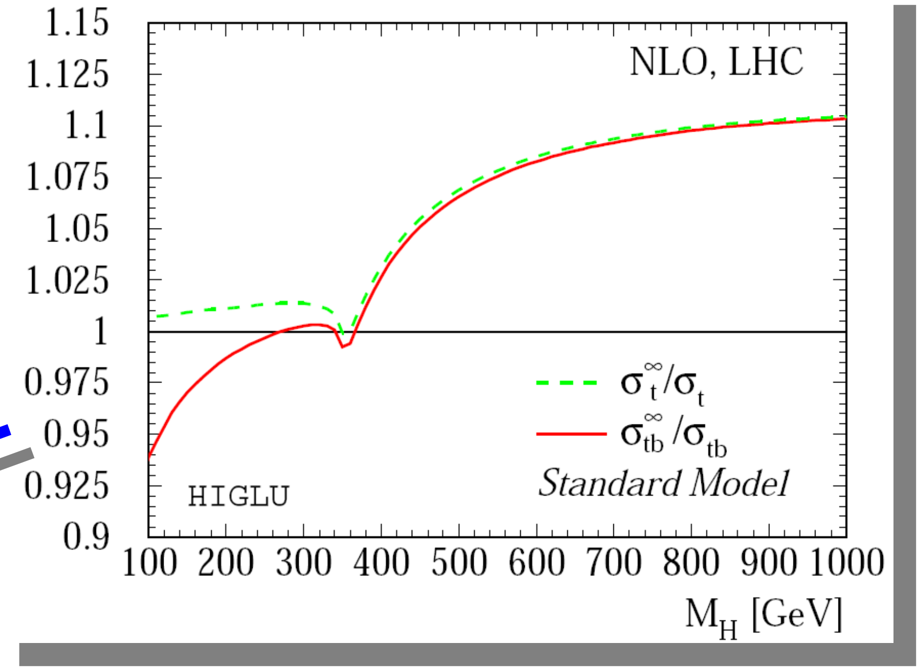
Why is the EFT approach so effective

NLO in the EFT approach: Dawson (1991); Djouadi, Spira, Zerwas (1991)

- Dominant terms to the cross section are the same in the exact and effective theory

very good agreement between $\sigma^{Exact,NLO}, \sigma^{approximate,NLO}$
provided we normalize to the exact LO result

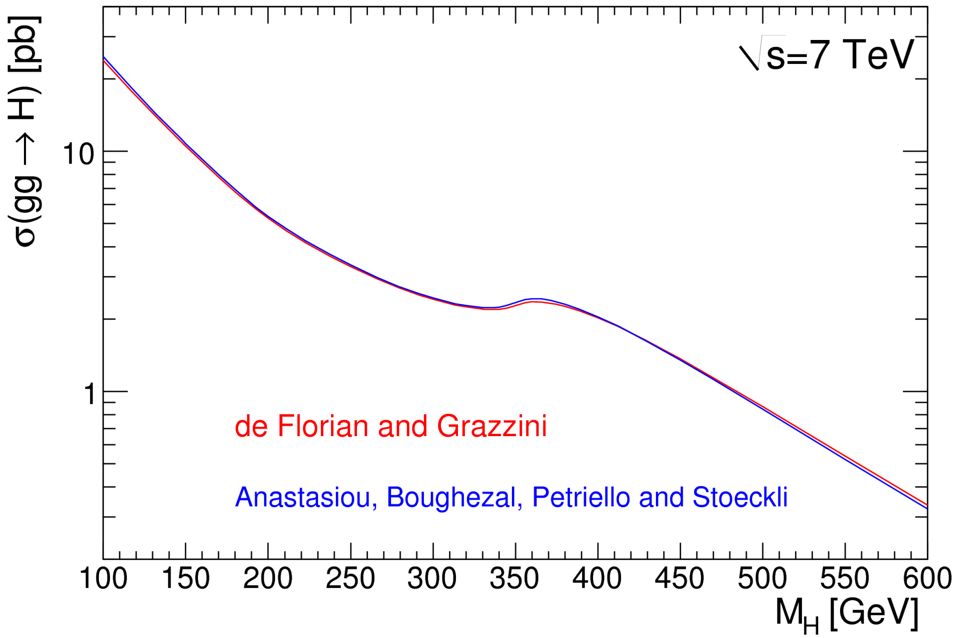
$$\sigma^{approximate}_{NLO} = \sigma^{LO}_{QCD}(m_t, m_b)\frac{\sigma^{EFT}_{NLO}}{\sigma^{EFT}_{LO}}$$



- difference < 10% for mH up to 1 TeV
  and < 1% below 200 GeV

- initial NNLO study of 1/mt supressed
  operators indicates this persists (Harlander et al; Pak et al, 2009)

Gluon fusion predictions: theory status



- NNLO QCD corrections increase xsection by 10-15% $\sigma = \sigma_0(I + I + 0.15 + \cdots)$
  - converging perturbative series
  - Reduction of renormalization and factorization scale dependence
- EW corrections increase NNLO xsection by 2-6%

Different theoretical approaches for producing Higgs predictions for gg->H were found to agree within a few percents

→ Theoretical predictions are well under control

Can we use these results to indirectly exclude new physics?

Beyond the Standard Model

- Properties of the Higgs boson can be modified in theories with additional particles
  - need precise predictions of cross sections to detect any deviations from measurements

- Higgs production via Gluon fusion is loop induced ⇒ very sensitive to new physics

- Lots of new physics to study, which Tevatron is already looking for:

  4th generation, colored scalar particles...

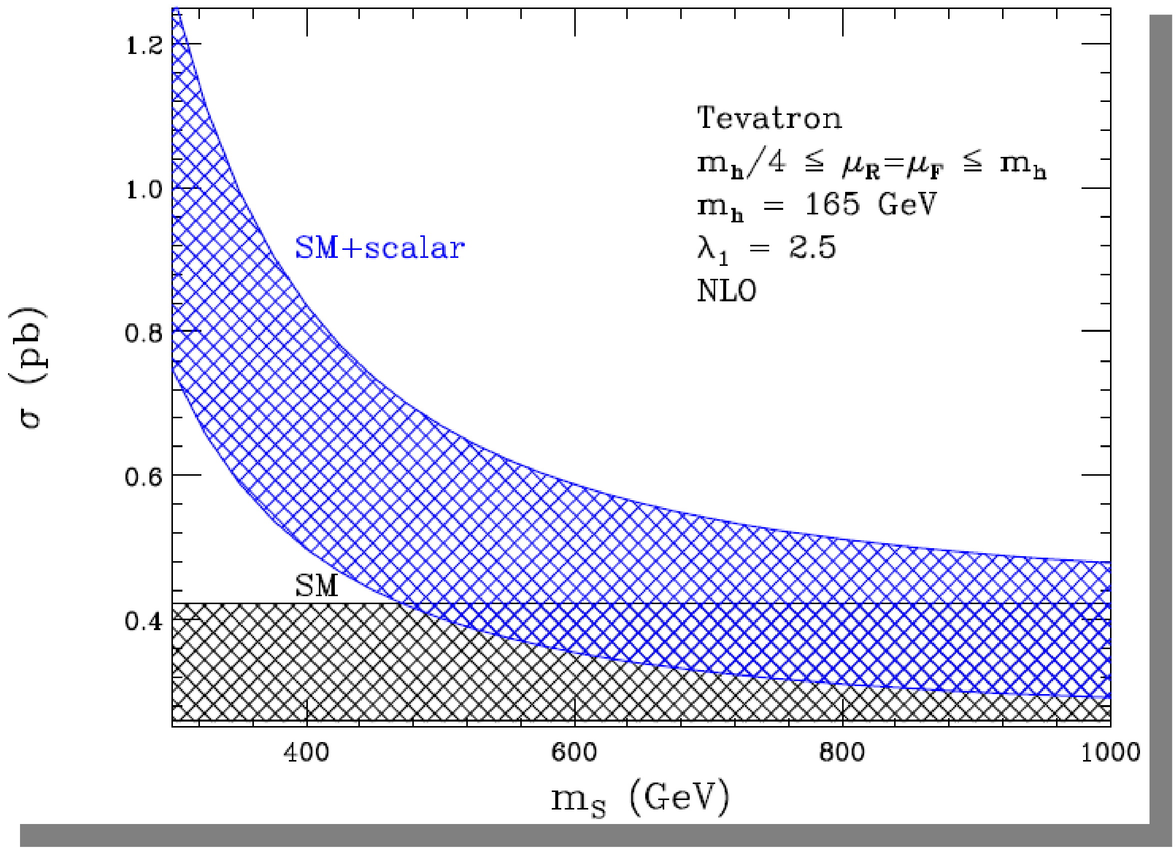
- They can couple to Higgs already at tree level and can modify the $gg \to H$ xsection

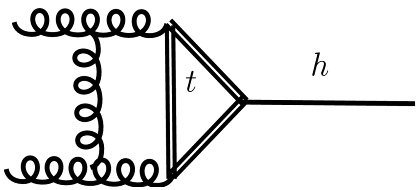
Example Studies:

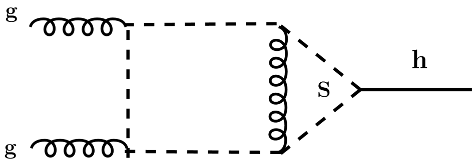
heavy Colored scalars effects on the cross section in the $gg \rightarrow H$ process

Details can be found in Phys.Rev.D81:114033,2010 & arXiv:1101.3769

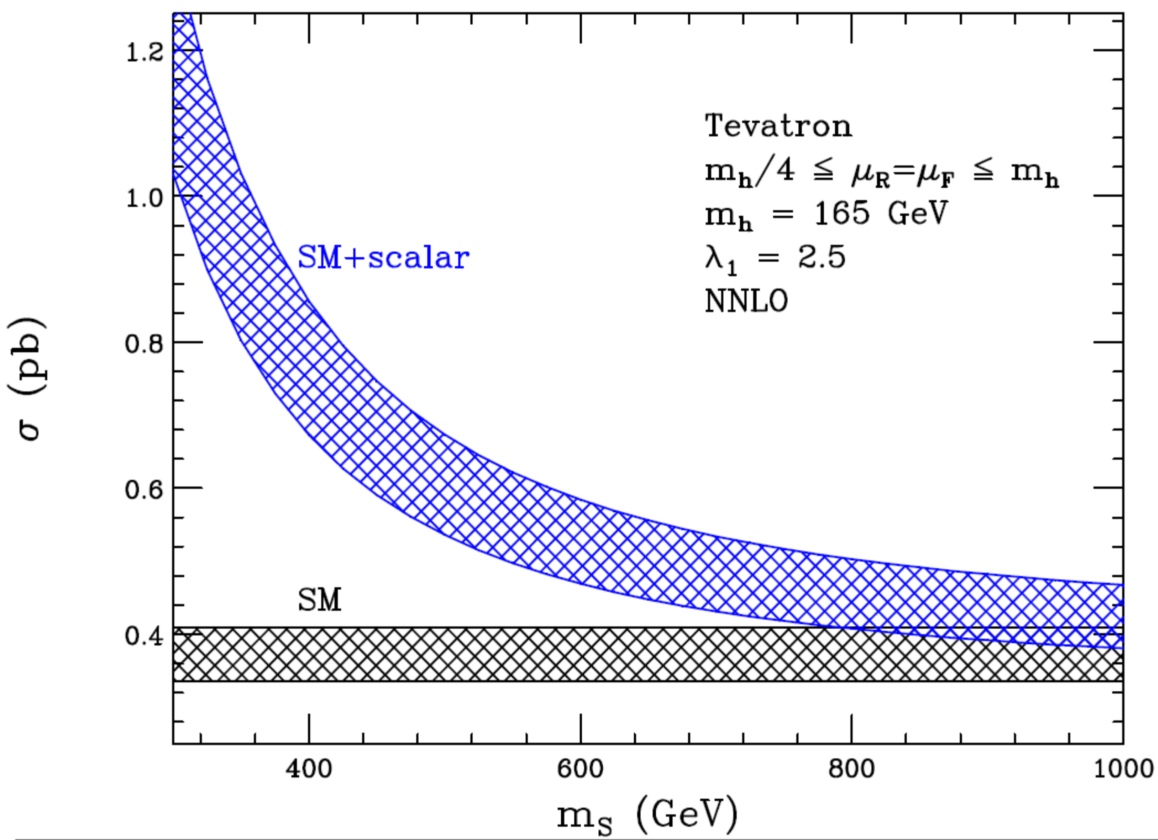
Color-adjoint scalar @ NLO

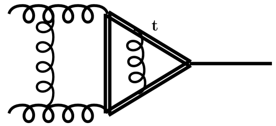


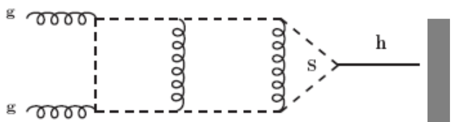


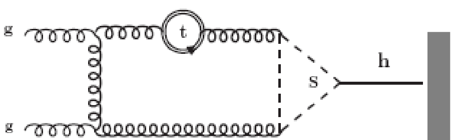


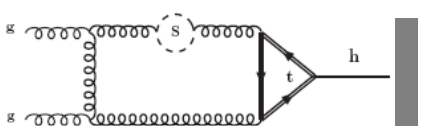
Color-adjoint scalar @ NNLO









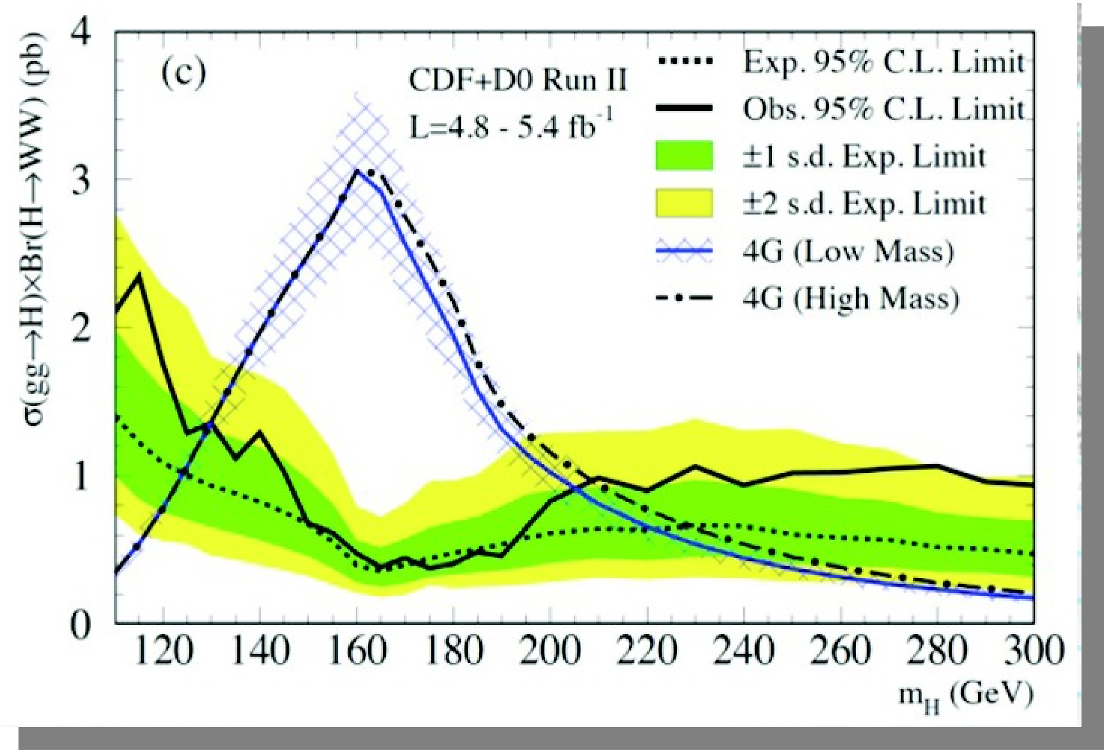


Only at NNLO a precise prediction is obtained → need NNLO for the indirect searches !

Fourth generation effects in gg → H

- QCD corrections to gg → H using a heavy doublet of quarks (T',B') exist

(Anastasiou, R. B., Furlan 2010)



- Assuming the existence of a 4th generation of fermions with large masses, a SM-like Higgs boson in the mass range 131-204 GeV is excluded

Model independent bounds on $\sigma(gg \to H) \times Br(H \to WW)$

A byproduct of the 4th generation analysis of Tevatron is this interesting table:

the observed 95% CL upper limit on

$$\sigma(gg \to H) \times Br(H \to WW)$$

Observed limit in pb

m_H [GeV]	Obs.
110	2.10
115	2.35
120	1.75
125	1.29
130	1.36
135	1.12
140	1.29
145	1.03
150	0.68
155	0.62
160	0.47
165	0.38
170	0.45
175	0.38
180	0.41
185	0.48
190	0.46
195	0.65
200	0.83
210	0.98
220	0.90
230	1.06
240	0.93
250	1.02
260	1.02
270	1.05
280	1.07
290	0.96
300	0.93

Various new physics models can be studied using these results

Constraints on heavy colored scalars from Tevatron's Higgs exclusion limit

Color octet & fundamental scalars in gg → H

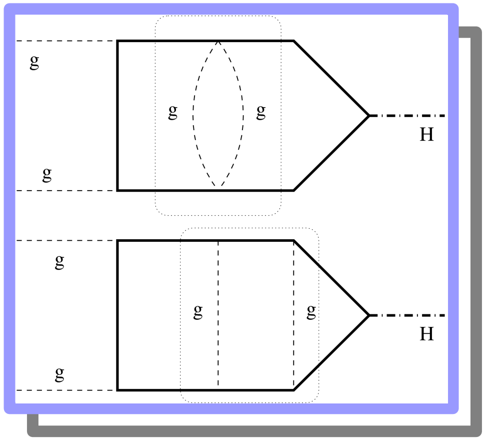
- Scalars that transform as $(8,1)_0$ and $(3,1)_0$ under $SU(3)\,x\,SU(2)\,x\,U(1)$

$$\mathcal{L}^{adj} = \mathcal{L}_{SM} + \mathrm{Tr}\left[D_\mu S D^\mu S\right] - m_S'^2\,\mathrm{Tr}\left[S^2\right] - g_s^2\,G_{4S}\,\mathrm{Tr}\left[S^2\right]^2 - \lambda_1 H^\dagger H\,\mathrm{Tr}\left[S^2\right],$$

$$\mathcal{L}^{fund} = \mathcal{L}_{SM} + \left(D_\mu S\right)^\dagger D^\mu S - m_S'^2\,S^\dagger S - \frac{1}{2} g_s^2\,G_{4S}\,\left(S^\dagger S\right)^2 - \lambda_1 H^\dagger H\,S^\dagger S.$$

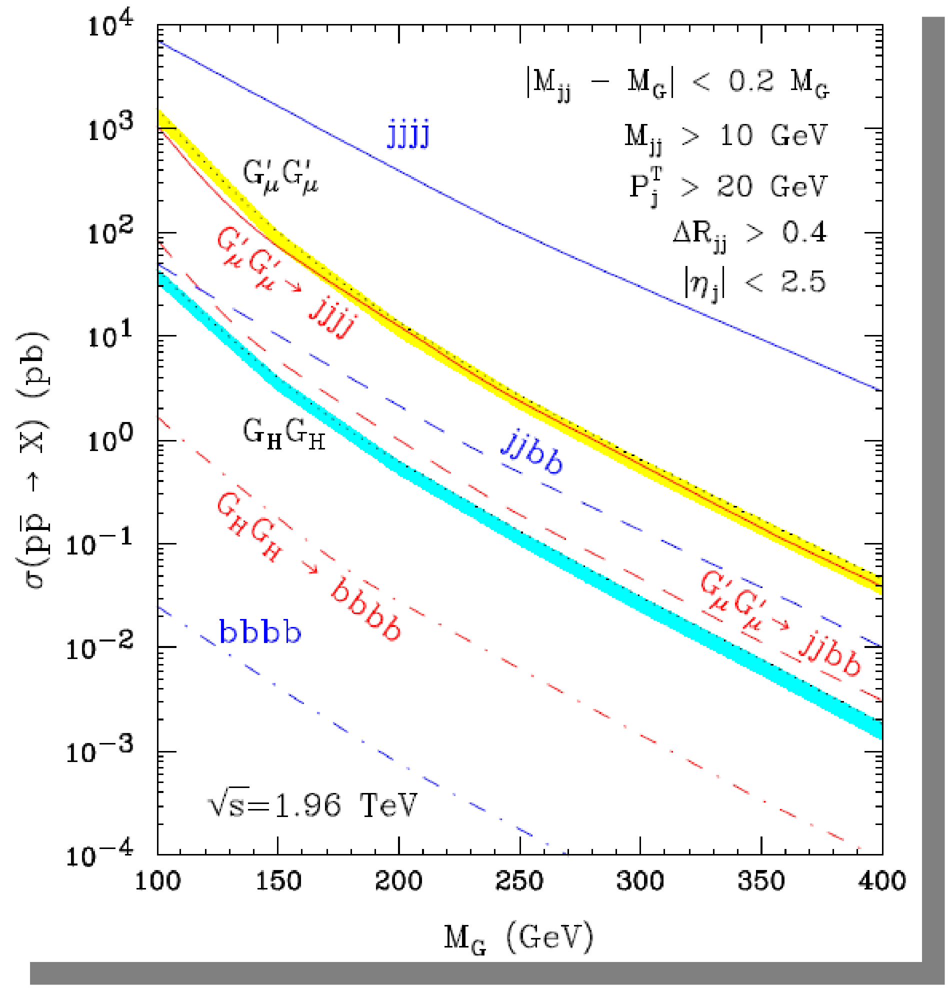
λ_1 allowed by all symmetries

G4S required by renormalizability at NNLO



Color octet scalars in gg → H

- Color octet scalars arise in theories with universal extra dimensions
- Primary decays expected to be into tt or bb depending on mS
- Can be searched for at Tevatron by looking for four b-jet final state, BUT direct search is difficult due to large QCD background
- Search reach at Tevatron estimated to be 280 GeV (Dobrescu, Kong, Mahbubani (2007))
- Can indirectly search for it using the influence of the scalar on Higgs production xsection



Dobrescu, Kong, Mahbubani (2007)

Extracting bounds on the scalars parameter space

- Use the following LO amplitude and nth order cross section:

$$\boxed{\mathcal{A}^{LO} = \mathcal{A}_t^{LO} + \mathcal{A}_b^{LO} + \mathcal{A}_S^{LO}}$$

$$\boxed{\sigma^n = \sigma_{t+S}^{LO}(m_t, m_S)\, K_{EFT}^n + \sigma_{Sb}^{LO}(m_S, m_b) + \sigma_{tb}^{LO}(m_t, m_b) + \sigma_{bb}^{LO}(m_b)}$$

NNLO

- Use HDECAY to produce the SM partial decay widths of the Higgs

$$\Gamma_{gg}, \Gamma_{\gamma\gamma}, \Gamma_{Z\gamma}, \Gamma_{WW}, \Gamma_{ZZ}\ , \ldots$$

- Replace Γ_{gg}^{SM} with the one that includes the scalar contribution Γ_{gg}^{new}

- The scalars increase the Higgs production cross section and the gg partial width

How does this change the BR(H → WW) ?

Extracting bounds on the scalars parameter space

Example: $\Gamma^{new}_{g\,g} = 5\,\Gamma^{SM}_{g\,g}$

MH = 120 GeV

$$Br\,(H \to WW)^{SM} = 0.13$$

$$Br\,(H \to WW)^{new} = 0.099$$

Roughly 25% decrease

MH = 165 GeV

$$Br\,(H \to WW)^{SM} = 0.9581$$

$$Br\,(H \to WW)^{new} = 0.946$$

Roughly 1% decrease

The branching ratio is mostly affected at low Higgs masses where it decreases significantly

Extracting bounds on the scalars parameter space

Two competing effects:

- an increasing cross section for all values of mH
- a branching ratio that decreases at low mH and remains almost unchanged at high mH

Implications:

- the stronger bounds are obtained at higher values of mH
- bounds at low values of mS (< 50 GeV) should not be taken seriously due to the limitation of the effective theory

Note: included a constraint $\frac{\Gamma_{tot}}{m_H} < \frac{1}{5}$ to prevent strong couplings

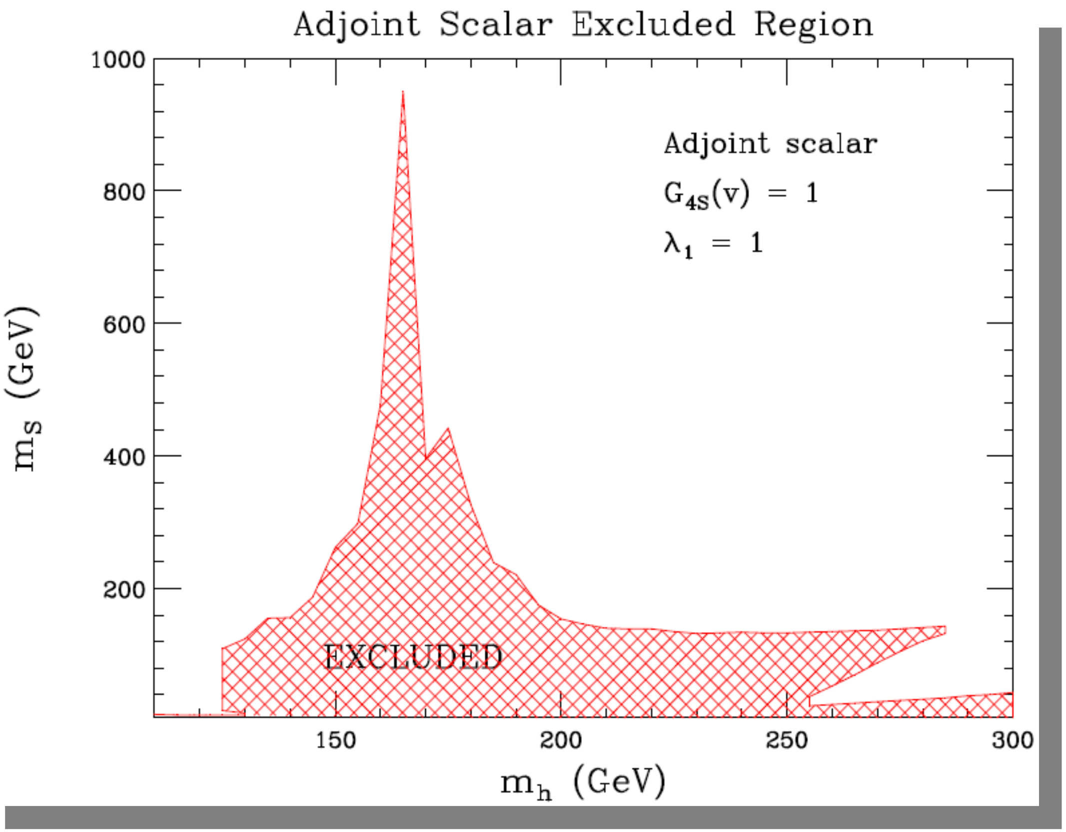
Extracting bounds on the scalars parameter space

- Strongest bound occurs at mH=165GeV

$$m_S^{adj} \geq 900\ GeV$$

- Excluded mS < 130GeV for
  135 < mH < 250 GeV

- Estimated direct search limit is 280Gev at Tevatron for scalars decaying primarily to bb



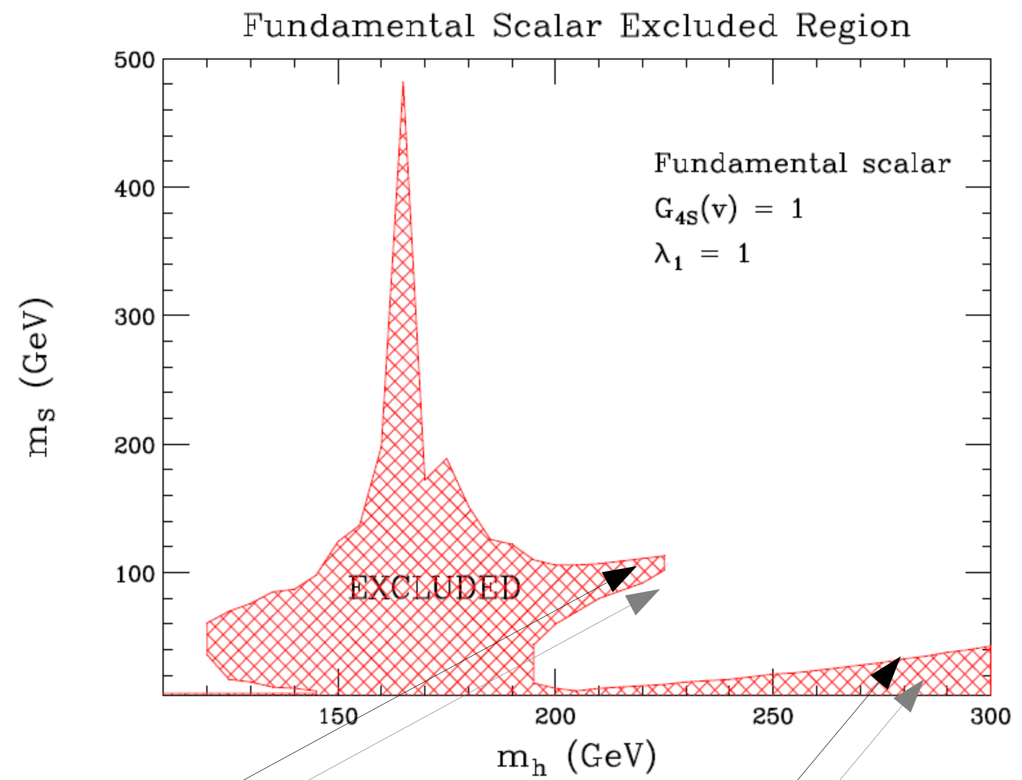
Direct search insensitive to mH and lambda but depends on the decay mode while indirect search is independent from the decay mode but sensitive to mH and lambda

Extracting bounds on the scalars parameter space

- Strongest bound occurs at mH=165GeV

$$m_S^{fun} \geq 500\ GeV$$

- Excluded mS < 100GeV for 150 < mH < 190 GeV



Threshold enhancement for Xsection for mH=2 mS

Tail comes from $\frac{\Gamma_{tot}}{m_H} < \frac{1}{5}$ constraint

Summary

- Direct and indirect search techniques are complementary for probing new physics parameter space

- The precision of the $gg \to H$ prediction in SM reached the level where new physics effects can not be washed out. This has become an additional constraint on physics Beyond the SM

- I have showed two example states that significantly alter the Higgs cross section: color-adjoint and color-fundamental states

  - strong constraints on their parameter space were obtained using Tevatron's exclusion limit for $gg \to H \to WW$

  - many other models involving heavy colored particles coupled to Higgs can be studied and constrained in a similar way

Backup Slides

Extracting bounds on the scalars parameter space

- The scalar sector is defined through the parameters $\lambda_{1,}\ G_{4S}\ ,\ m_S$
  - Use RGE to get the allowed values of G4S by demanding absence of Landau pole up to 10 TeV:

    - adjoint scalar G4S(v) <1.5

    - fundamental scalar G4S(v) < 2.5

    we chose G4S = 1 and checked that other values in the allowed range change the bounds by at most 5%

  - There is no symmetry reason to expect λ_1 to be small.
    we chose $\lambda_1 = 1$ for simplicity